

The Orion Pad Abort 1 Flight Test

A Highly Successful Test

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The Orion Pad Abort 1 (PA-1) flight test was designed as an early demonstration of the Launch Abort System (LAS) for the Orion capsule. The LAS was designed developed and manufactured by the Lockheed Martin/Orbital Sciences team. At inception it was realized that recovery of the Orion Capsule simulator would be useful from an engineering analysis and data recovery point of view. Additionally this test represented a flight opportunity for the Orion parachute system, which in a real abort would provide final landing deceleration.

The Orion parachute program is named CPAS (CEV Parachute Assembly System). Thus CPAS became a part of the PA-1 flight, as a secondary test objective. At program kick off, the CPAS system was in the design state described below. Airbag land landing of the spacecraft was the program baseline. This affected the rigging of the parachutes. The system entry deployment conditions and vehicle mass have both evolved since that original design.

It was decided to use the baseline CPAS Generation 1 (Gen 1) parachute system for the recovery of the PA-1 flight. As CPAS was a secondary test objective, the system would be delivered in its developmental state. As the PA-1 program evolved, the parachute recovery system (CPAS) moved from a secondary objective to a more important portion of the program. Tests were added, weights and deployment conditions changed and some hardware portions of the CPAS configuration were not up to the new challenges. Additional tests were added to provide confidence in the 'developmental system'.

This paper will review a few of these aspects with the goal of showing some preliminary and qualitative results from what we believe was a highly successful test.

I. Parachute System Overview

This section will contrast the PA-1 Gen 1 configuration with later configurations and reflect the challenges encountered by applying an early point design to the evolving spacecraft and spacecraft flight conditions and environments.

In general, the CPAS system has remained largely Apollo-like in configuration using the following primary parachute stages:

- 1) Drogue parachutes for deceleration and capsule stabilization
- 2) Drogue release followed by pilot parachute deployment (mortars)
- 3) Main parachute deployment by pilot parachutes
- 4) Descent under main parachutes

Figure 2 provides an illustration of this sequence.

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- 1 – FWD Bay Cover Release
- 2 – Drogue Deployment
- 3 – Drogue Inflation
- 4 – Drogue Release – Pilot Deployment
- 5 – Main Bag Extraction
- 6 – Main Parachute Deployment
- 7 – Touchdown

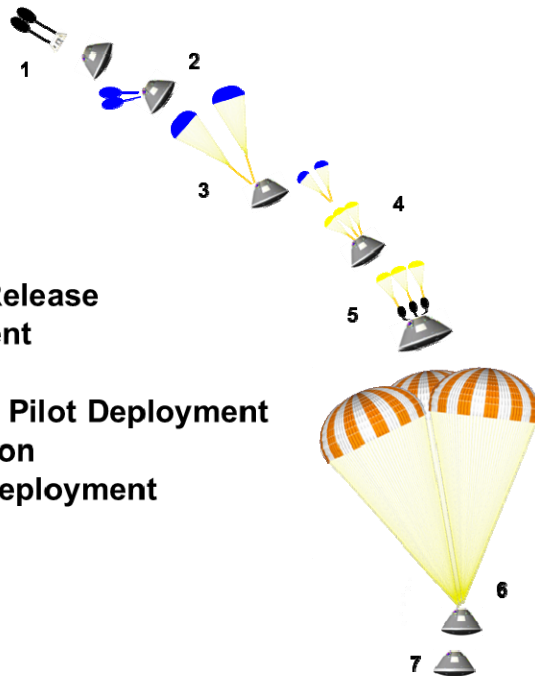


Figure 1 – Basic CPAS/Apollo Parachute Sequence Nominal Entry

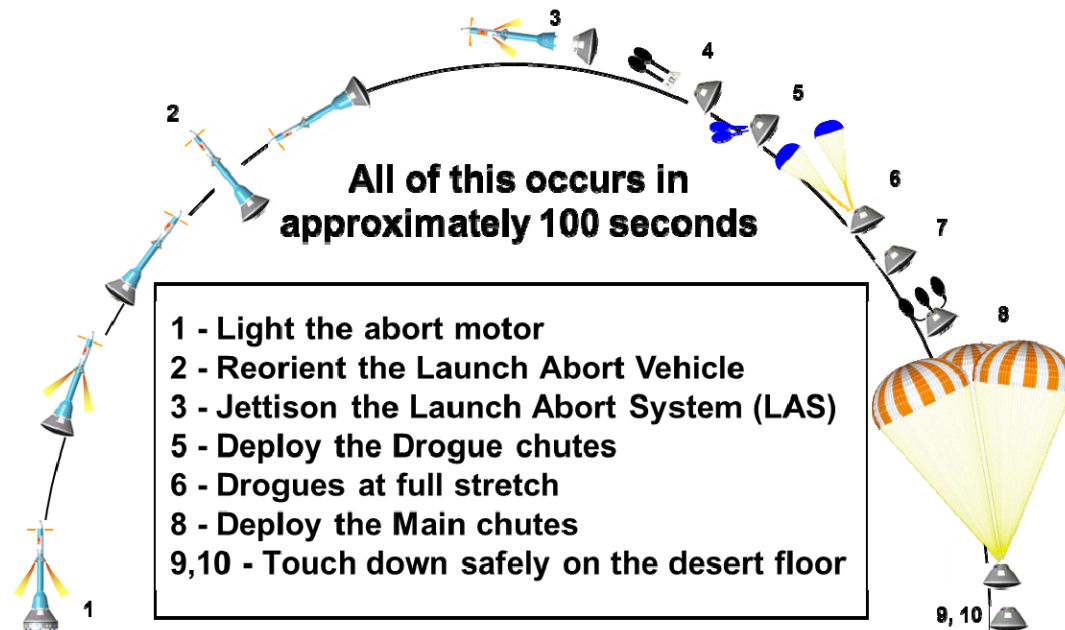


Figure 2 – Launch Abort Parachute Sequence

II. PA-1 Configuration

At the time of CPAS inception into the PA-1 program, the Orion landing baseline was land landing on airbags. This required a rather flat hang angle of the capsule under parachutes and the necessity of a harness and confluence system to provide the flat hang angle under main parachute. Figure 3 provides a schematic of the harness and confluence system required to provide the desired hang angle.

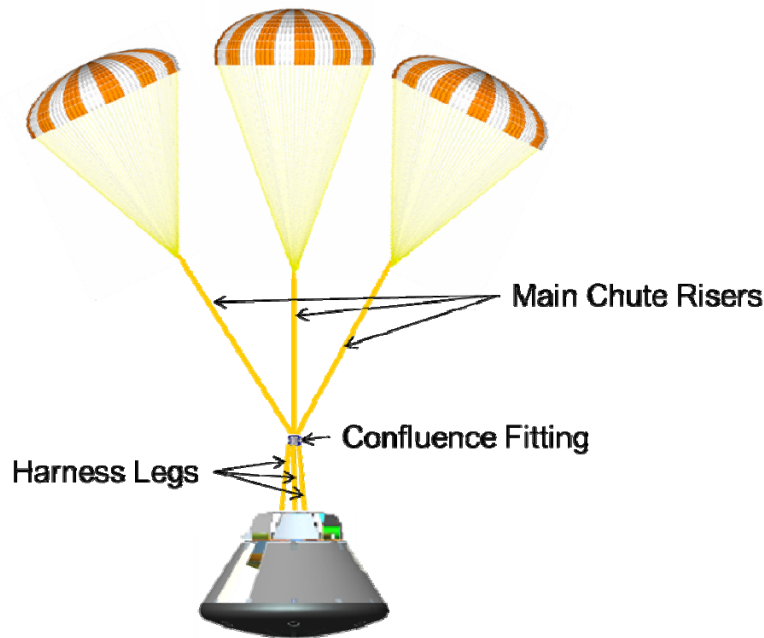


Figure 3 - Schematic of Harness and Confluence System

While this configuration differs from the final Apollo configurations, it is not without precedence. The early Apollo Block 1 systems used a very similar system. Unfortunately, the Apollo program experienced a rather spectacular failure in early testing and quickly moved away from confluence fittings. That being said, the PA-1 flight was set on this path and changing to another attachment scheme represented impacts to the parachute system and the spacecraft simulator structure. And at this time, this remained the baseline for the objective spacecraft. One specific challenge was the stowage and deployment of the confluence fitting which is discussed below. Figure 4 presents a pair of photos, one of the basic confluence fitting and another of the fitting stowed in the PA-1 spacecraft simulator as rigged for flight.

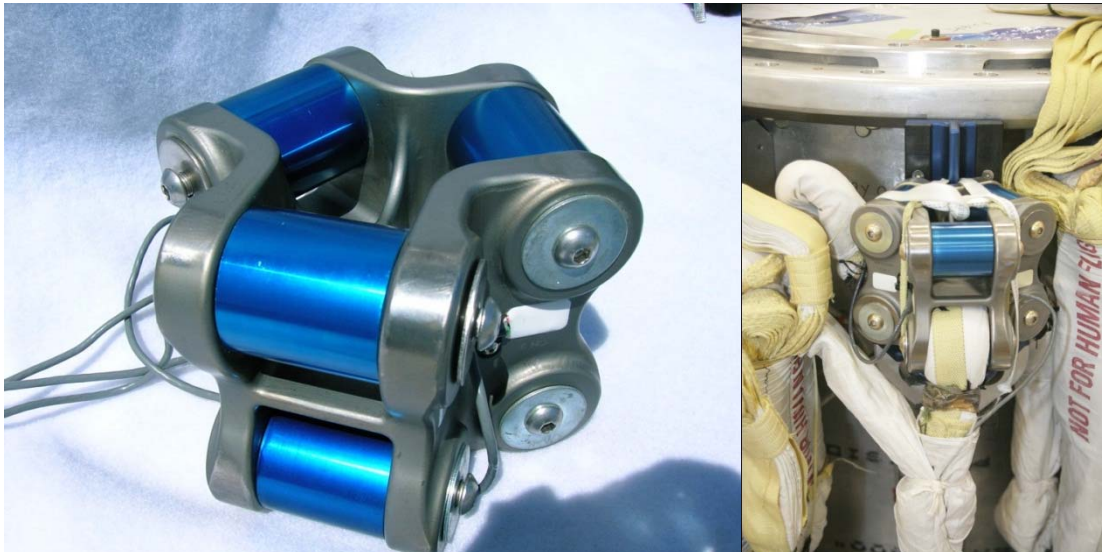


Figure 4 -Confluence Fitting and Fitting Stored in Spacecraft

III. Current Orion Configuration

As the program has evolved, the baseline has moved from land landing to water landing. This trade is mostly driven by weight for the landing system and the limited value of system reuse for a limited number of flights. As a result of the water landing decision, the spacecraft now requires a hang angle under main parachutes similar to the 27 degrees employed in the Apollo program. This allows the edge of the capsule to ‘knife’ into the water to reduce entry loads.

This requirement suggests a single parachute attachment point to the spacecraft (ala Apollo) rather than the harness arrangement employed for PA-1. This approach greatly simplifies the parachute rigging, perhaps provides some additional capsule dynamics, but in general in a reliability enhancement over the harness/confluence fitting approach. Figure 5 provides a schematic indicating the single point attach and the spacecraft hanging from a single point.

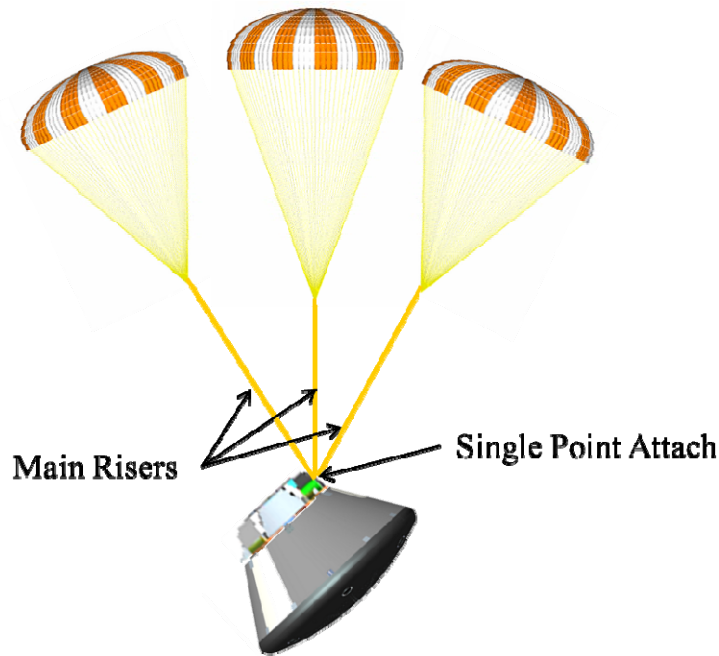


Figure 5 -Single Point Parachute Attachment Schematic

IV. Parachute System Limitations and Work Around

As the PA-1 flight test and the Orion system evolved, there were a number of areas where the CPAS Gen-1 parachute system began to fall short of the current requirements. Not because the Gen-1 system was lacking from any point of view, but rather because the Gen-1 system was anchored in a point in time while the spacecraft and the related PA-1 flight experiment moved further through the development process. Major variables were weight, parachute deployment airspeed and abort trajectory and timeline. Additionally, the integration of the parachute system with the spacecraft evolved during this period as well.

V. Parachute System Integration

Integration of the parachutes into the PA-1 vehicle was a cooperative effort with Lockheed Martin. Several instances occurred which required the parachutes and harness components to be fully integrated to the vehicle. These dry run integrations provided an improvement process in which the parachute system was now fully exposed to all components that were installed into the bay. This included other flight systems such as LAS hardware and flight guidance systems. This was the first time that CPAS would be fully integrating into a vehicle alongside all the flight subsystems. After each integration, the CPAS team would hold discussions with the vehicle team. Ideas for improving reliability of the systems were passed back and forth between the teams, ultimately deciding what actions could be accomplished for improved reliability, i.e. rounding exposed edges and including protective bars or ramps. These design traits were then included into the PA-1 vehicle design. Afterwards the integration of CPAS would

occur again and any improvements would be discussed. Some changes were not only to the vehicle but to the CPAS system itself. For example it was found that during installation, the harness leg stowage bag hung down much lower in the PA-1 vehicle due to the location of other subsystems in the area. A design change was made to include a keeper that was added to the harness leg stowage bag to pull it free from interference. That keeper can be seen in Figure 6.



Figure 6 - Keeper Installed

In addition during the integration dry runs it was noted that the length of riser that could be stowed outside of the drogue mortars should be lengthened. This allowed for a safer installation of the ordnance into the drogue mortars. This was a simple integration change to make and was incorporated for the flight integration.

A total of three integration dry-runs were completed prior to the final installation of CPAS for flight. This level of interaction with the vehicle community led to a very reliable integration of CPAS for the PA-1 test. This also allowed for a close working relationship with other subassemblies to help determine what those subassemblies design drivers were. This helped in creating better designs as a whole system in future iterations.

VI. Confluence Stowage and Deployment

The stowage and deployment of the main parachute confluence fitting involved a tray to mount the system and stowage tie and release system (Figure 7). This was a concern due to the significant vibration environment created by the launch abort motors. Additionally, the deployment of the main parachute harness and confluence fitting represents a significant problem in parachute energy management. If the parachute deploys and begins to inflate before the confluence is deployed and the harness is erected, significant inertial related loads can be created and these can exceed the basic design loads for the parachute system.



Figure 7 - Main Parachute Confluence Fitting in its Stowage Location.

In the end two risk mitigations were employed. The first was a set of tear webbing attenuators which provided a reduced but positive force to deploy the confluence fitting and erect the main parachute harness. While bulky, and rather inefficient, these devices helped to manage the inertial loads during this critical portion of the main parachute deployment. Figure 8 presents a view of these during integration for the PA-1 flight test.



Figure 8 - Main Parachute Confluence Fitting with Attenuators

Secondly, a vibration test was conducted on the confluence fitting and its shelf to confirm that the baseline retention system was adequate. Although the vibration environments were pretty strong, the parts survived and were cleared for the flight test. To reiterate, these parts were design well ahead of the flight test and had to be reviewed again in the light of new environments and other requirements. Figure 9 provides an image of the confluence fitting and mounting tray preparing for vibration testing.

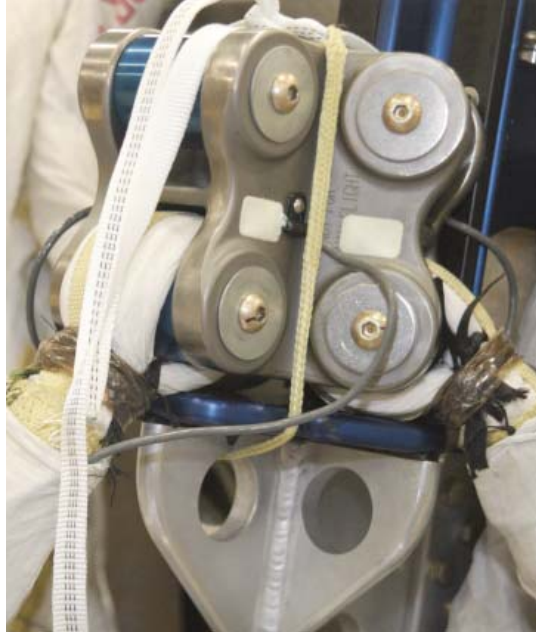


Figure 9 - Main Parachute Confluence Fitting and Mounting Tray Preparing for Vibration Testing

VII. Drogue Structural Margin

As the program evolved, the capsule weight and capsule dynamic pressure at deployment increased, eventually pushing the parachute inflation loads above the capability of the Gen 1 parachutes. A number of solutions were considered including new parachutes – cost and schedule tended to prohibit this. Finally, the solution selected was to reef the drogue parachutes on a special schedule which reduced the loads to tolerable levels. Additionally, the parachute stress analysis was calculated using actual material strengths in the parachute rather than specification minimum strengths. As with many parachute fabrics, most of the materials delivered are 10% over the specification minimum while meeting or beating the specification maximum weight. This approach allowed CPAS to re-capture some parachute capability in terms of loads, while retaining the positive margins required by the program.

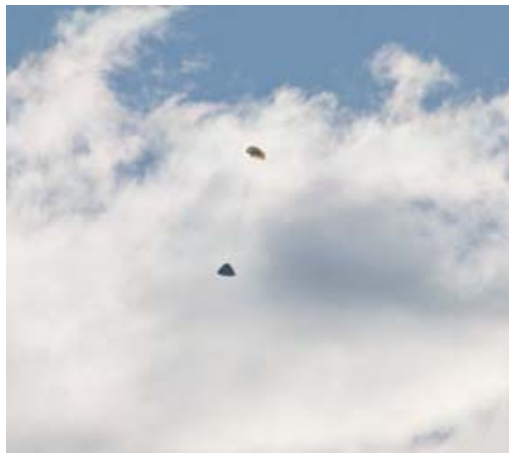


Figure 10 - Provides a View of the Drogue Parachutes in Flight during the Mission

VIII. Pyrotechnic System Qualification Level

The developmental status of the CPAS pyrotechnics, namely the parachute mortars, was not acceptable to the NASA Engineering Pyrotechnic community. Eventually, addition environmental tests were added to provide confidence in the PA-1 pyro systems. These tests included vibration and shock testing of the parachute mortar assemblies, and some component level testing of gas generators and reefing cutters. Additionally, a 40 ft drop test was performed on the gas generators to assure that they would not activate following such a drop.

All tests were completed successfully and concluded with live (static) firings of the parachute mortars at JSC. Figure 11 provides an image from one of the parachute mortar tests.



Figure 11 - Drogue Parachute Mortar during Static Firing

IX. Test Results

The detailed test results from the PA-1 flight are still being analyzed and reviewed. However, we can report that the parachutes were recovered in pristine condition with no evidence of flight damage. The parachute trajectory including reefing stages, flight time, etc, appears to have been nominal.

A special “hats off” to the Lockheed/Orbital team for the LAS performance. That device placed the parachute system where it had the best chance to succeed.

X. Summary

In summary, the PA-1 flight test appears to have been highly successful, and the parachute portion performed to plan. Recovery operations for the parachutes was challenging at times due to the terrain, but generally the mission went as planned. We look forward to future tests as we work towards a future operational system for the United States, that once again includes a crew escape or launch abort capability.